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CONVAIR DIVISION OF GENERAL DYNAMICS CORPORATION

ZERO-G REPORT

LIQUID/LIQUID MODELS

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1.0 INTRODUCTION:

The Centaur is in a weightless or free fall condition during almost its entire flight. The thrust periods are relatively short. A zero-g test program was undertaken to investigate liquid behavior and boiling heat transfer using drop tests and airplane flight trajectories, but both methods had serious limitations. Only short zero-g test times could be achieved. The periods were long enough to allow useful heat transfer data to be collected and to show the behavioral tendencies of the liquid. The liquid configurations toward which these tendencies pointed could be estimated, but they could not be clearly delineated. The liquid/gas interface in zero-g seemed to distort itself toward the mathematically derived shapes (Ref. A), but a test method was needed to demonstrate the equilibrium configuration clearly for a comparison of theory with reality.

This report describes the liquid/liquid zero-g models which allow such a comparison to be made and which, in addition, can be used to determine the shapes of zero-g liquid/gas interfaces more easily than they can be calculated, especially in complex static situations.

2.0 PREPARATION OF MODELS:

The required static zero-g demonstration was provided by "liquid/liquid" models. These contain two liquids which do not mix. The liquids were basically oil and water and were adjusted to have the same density by small additions of a heavy or light component to the oil or the water as required. The equality of the density, i.e., the "Balance", was judged by noting which liquid rose or sank through or around the other. Two rather different basic systems were used.

In one of these, distilled water forms the ullage bubble and the surrounding liquid is a mixture of oils. Typically, a light hydrocarbon such as hexane, stoddard solvent or kerosene is the base oil to which is added a heavy, low viscosity liquid such as benzene, carbon disulphide, trichlorethylene, or Freon TF. In an alternate system, the bubble contains kerosene, and the surrounding liquid is a mixture of methyl alcohol plus a little water. The decision as to whether the oil is in the bubble or around it is made by the liquids themselves on the basis of their surface energies. The liquid which wets the walls more readily surrounds the other. The "oil outside" system has the disadvantage that the water occasionally breaks through the surrounding oil and wets the wall. The "oil inside" system was much better in this respect, but it had another drawback. Some of the kerosene would dissolve in the mixture; a drop in the temperature of the model would then precipitate the kerosene out of the alcohol/water mix in the form of a fog which took an unacceptably long time to clear up.

(Continued)

2.0 PREPARATION OF MODELS: (Cont)

The optical properties of the models were found to be of some importance. Looking in through the side of a beaker of water, only part of the contents can be viewed simultaneously. We found the accompanying distortion to be considerable with all normal liquids. It was greatly reduced by using a container with flat faces. For our purpose, however, the internal surfaces could not be flat, for the configuration was scaled down from the Centaur LH_2 tank. We machined the models square outside and round inside out of Lucite or Plexiglas and attempted to avoid the optical difficulties by selecting an outer fill liquid whose index of refraction matched that of the model ($n = 1.5$ approx.). This could be achieved with the "oil outside" system, but only temporarily.

Carbon disulphide/benzene mixtures produced beautiful models but the benzene quickly dissolved the Plexiglas. Carbon disulphide/stoddard solvent mixtures were also optically satisfactory, but the CS_2 decomposed and turned yellow with exposure to light, and it tended to crack the Plexiglas. Freon TF and trichlorethylene were stable and did not damage the models but produced some optical distortion because their indices of refraction were less than that of the Plexiglas.

Various surface treatments and liquid additives were triedin an attempt to prevent the water from wetting through the oil mixture. No fully satisfactory solution was developed, but reasonable results were achieved by coating the inside of the container with Shinola shoe polish or a silicone grease and then rinsing the model with stoddard solvent. The models were then quite satisfactory when filled, but in a day or few the oil mixture would pick up a fluffy precipitate.

(Continued)

2.0 PREPARATION OF MODELS: (Cont)

The best anit-wet-through agent we found was a proprietary thread cutting fluid - Tapmatic. This produced some precipitate but rather less than the waxing processes. One general conclusion we reached was that cleaning the inside of the models should be avoided as much as possible. The plastic surface in contact with the oily mixture seems to develop an affinity for the oil. We never really understood the surface physical chemistry; our approach was admittedly alchemical.

We made Centaur LH_2 tank models in sizes ranging from one thousandth to one tenth of full size. The largest model also had a LO_2 tank. Some views of the models are shown in Figures 1, 2, and 3.

3.0 JUSTIFICATION:

A trained technical man, seeing the liquid/liquid models on the desk, is normally interested in the zero-g demonstration, but by nature and training he is suspicious of the simulation. The following chain of reasoning was assembled in an attempt to allay such doubts.

A. The Centaur fuel tank contains two and only two fluids (LH_2 and GH_2). So does the model (oil and water).

B. An interface having uniform tension separates the two fluids (Centaur or model).

C. Gravity has the same effect on the two fluids and therefore has no effect on their relative configuration or position. (The orbiting Centaur is allowed to accelerate without restraint. The oil mixture in the model has the same density as the water).

(Continued)

3.0 **JUSTIFICATION:** (Cont)

D. One of the fluids (LH_2 in the Centaur, oil in the model) preferentially wets the wall and with so much enthusiasm that the interface/wall contact angle is essentially zero.

Summarizing, surface tension provides the only forces available to affect the static distribution of the fluids in the tank. It acts similarly in the orbiting vehicle and the model, and the equilibrium configurations of the fluids are therefore similar.

4.0 **APPLICATIONS:**

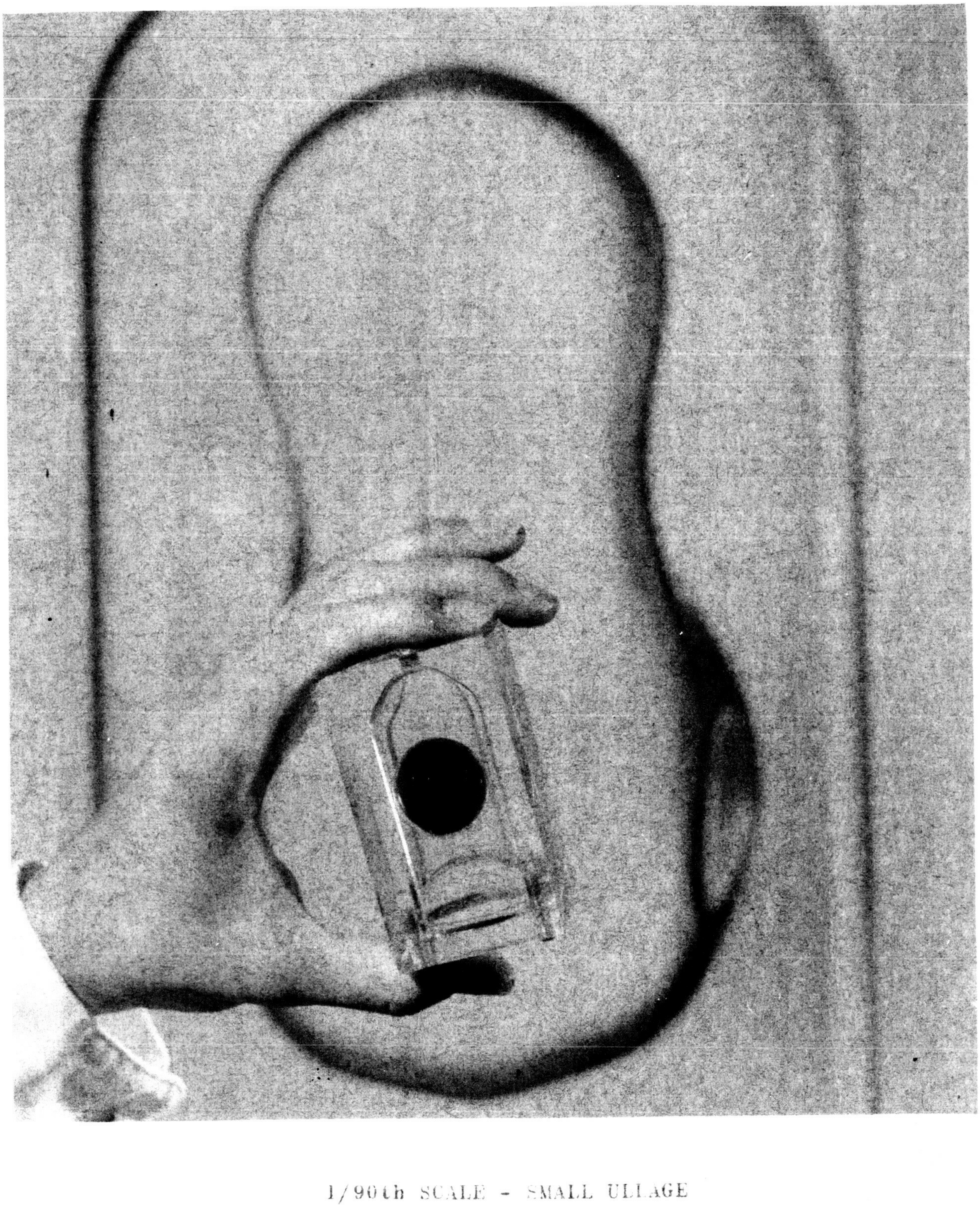
The liquid/liquid models have been used for demonstrations of general zero-g liquid configurations to small and large groups of people. They have also served to investigate the effect of structures inside the tank (baffles, probes, etc.) on these configurations. They were used in a special dynamic application to corroborate the zero-g liquid behavior scaling principles (Ref. B) and as an aid to visualization of the shape of the liquid/gas interface around a "Center Vent" for the Centaur LH_2 tank (Ref. C). In addition, they have helped many engineers and scientists to appreciate how liquids behave in free fall. For example, it was recognized early in the program that structures projecting into the LH_2 tank, being wetted by the liquid, will gather liquid around them.

4.0 APPLICATIONS: (Cont)

The liquid/liquid models suggested instead the viewpoint that the projections, pushing on the liquid/gas interface, hold the ullage gas away unless this gas be broken up into bubbles which can fit loosely between the projections. This concept was used in the assessment of LH_2 tank bubble accumulation (Ref. D) in liquid/liquid models.

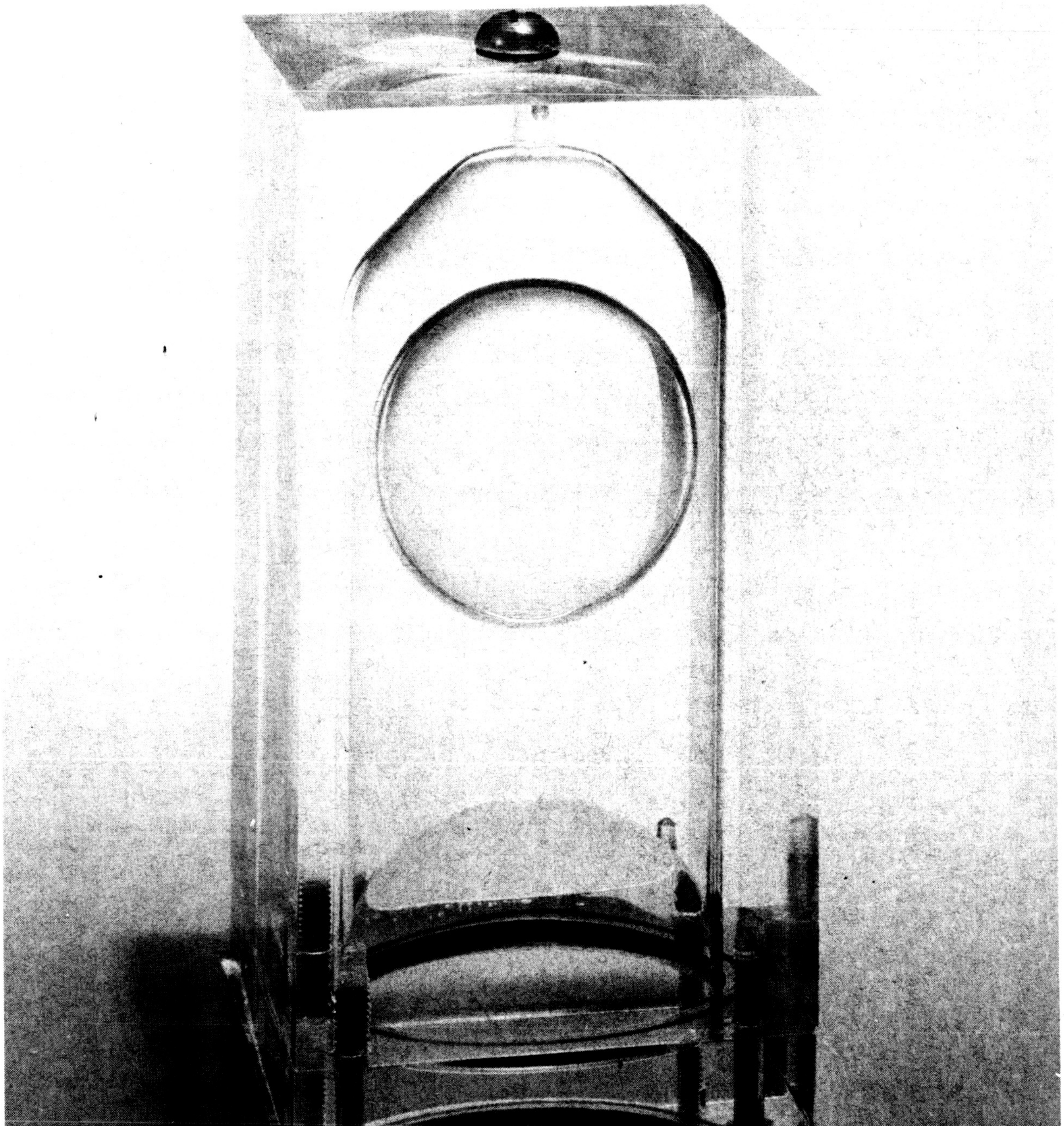
The liquid/liquid models were created as a test or experiment. The general zero-g liquid configurations were so apparent that the experiment almost immediately became a demonstration, and later a show.* There is an old saying about the ten thousand word value of a picture. We would extend this. To see the reality, or near reality as in the liquid/liquid models, is worth ten thousand pictures. Anybody working on zero-g liquid behavior should have a chance to take a liquid/liquid model in his hands and to push the bubbles around.

(*) -- General Dynamics/Astronautics exhibit at the A.R.S. show in the New York Colisum in October, 1962.



1/90th SCALE - SMALL ULLAGE

Figure 1



1/60th SCALE - SMALL ULLAGE

Figure 2

1/35th SCALE - 70% ULLAGE

Figure 3

R E F E R E N C E S

A) Ta Li; GD/A Report: "Liquid Behavior in A Zero-G Field"; GD/A Report # AE 60-0682

B) Hansen, J. L.; Zero-G Report: "Liquid Behavior Scaling"; Test Laboratories Report # 55D859-8; May 1962

C) Perkins, C. K.; Zero-G Report: "The Center Vent Shape"; Test Laboratories Report # 55D859; July 1961

D) Tuck, G.; Zero-G Report: "Bubble Accumulation in Simulated Boiling"; Test Laboratories Report # 55D859-6; May 1962